Helium removal from the gas mixture by the Condenser Booster

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Abstract

- Input gas mixture: **Ar 5%; He 85%; N2 10%**
- The volume of the condenser booster is **20 liters**
- We will pressurize the Condenser Booster with the gas mixture up to **200 bar**.
- We cool the mixture of gas to a temperature just above the crystallization temperature of the Ar-N2 mixture. In this calculation we assume that this temperature is 65 K.
- We remove the He gas and live the liquid fraction (Ar and N2) inside the booster.
- We continue this process of the gas mixture introduction through valve PV-71, liquefaction of argon and nitrogen and successive removal of gaseous helium, until to accumulate approximately 15 l of liquid mixture of Ar and N2. It is not necessary to add the tube that sends the gas on the bottom of the booster, because the introduction of the gas and the expulsion of helium happen in separate times.
- We heat in controlled way the liquid mixture and, again, through valve PV-71 we fill up bottles with Ar and N2 to 200 bar

According with this exercise we need about 100 l of LN2 to condensate, inside the booster, 16 l of a mixture of liquid Ar and N2 (4.6 l of LAr and 11.4 l of LN2, the ratio between the two components depends on the composition of the original gas mixture). Naturally it must add the liquid nitrogen necessary to cool the booster.
The weight of 16 l of this mixture is 15.7 Kg and the Ar fraction is 6.5 Kg The esteem of the production rate of the liquid mixture is about 40 g per minute. It depends mainly on the pumping speed of the apparatus that pumps on the LN2 and on the thermal coupling between the LN2 and the gas mixture inside the booster. This calculation assume a pumping speed of 10 l/s = 36 m^3/h.

Helium separation procedure

1. **Load** (by the valve PV-71) **the 20 l volume of the booster with the gas mixture at 200 bar.** The valve PV-71 is shut when the pressure reaches 200 bar.

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	4000	178.4				
Ar	200	8.9	356	23	57	0.256
N2	400	17.8	500	78	99	0.618
He	3400	151.7	607	400		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 657KJ. Let's assume 800KJ to account for other heat loss. It is necessary boiling 4.0 Kg (5.0 l) of liquid N2 = 143 mole = 3200 bar l. Assuming that the **pumping speed** of the vacuum system, that keeps the liquid nitrogen in the booster dewar at 0.3 bar, is **10 l/s**, it removes 3 bar l/s.

It will take about 20 min to fill the booster with 4000 sl of gas mixture, to cool the He at 65K and to liquefy the Ar and N2 fractions.

When the temperature of the booster reaches the stable value of 65K, the pressure of nitrogen in the dewar reaches its minimal and stationary value. The dewar should be refilled with LN2 during the cool down process. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The Ar vapor pressure at 65K is 0.04bar. The volume available for the gas phase is 19.1 l

2. **Remove the He fraction from the booster**. After reaching the equilibrium condition at 65K, keeping the PV-71 valve closed, we open the valve to remove the He fraction from the booster. Please note that this valve must be added to the Condenser Booster drawing. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Argon lost** sl
Ar	200	8.9	356	0.256	0.76
N2	400	17.8	500	0.618	
He	79	3.5	14		

The volume available for the new gas is 19.1 l. We make another condensation process loading this volume with the gas mixture

3. **Load the 19.1 l volume of the booster with the gas mixture at 200 bar**

Open the PV-71 valve, slowly feel the booster at 200 bar. During this refill the temperature should remain near 65K, so the gas mixture will enter the booster with a flow rate compatible with the pumping speed of the dewar vacuum system. The amount of gas that will enter the booster this time is 19.1 l x 200 bar - 79 sl = 3740 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3740	166.9				
Ar	187	8.3	332	22	53	0.239
N2	374	16.7	468	73	93	0.578
He	3179	141.8	567	374		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 614KJ. Let's assume again 800KJ to account for other heat loss. It is necessary boiling 4.0 Kg (5.0 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 18.3 l.

4. **Remove the He fraction from the booster**. After reaching this equilibrium condition at 65K, keep the PV-71 valve closed and open the valve to remove the He fraction from the booster. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost sl**	**Total Ar lost sl**
Ar	387	17.3	691	0.496	0.73	1.49
N2	774	34.5	967	1,195		
He	77	3.4	14			

The volume available for the new gas is 18.3 l.

5. **Load the 18.3 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 18.3 l x 200 bar - 77 sl = 3583 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3580	159.7				
Ar	179	8.0	320	21	51	0.229
N2	358	16.0	448	70	89	0.553
He	3042	135.7	543	358		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 589KJ. Let's assume 700KJ to account for other heat loss. It is necessary boiling 3.5 Kg (4.4 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 17.5 l.

6. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost sl**	**Total Ar lost sl**
Ar	566	25.2	1007	0.723	0.7	2.19
N2	1132	50.5	1414	1,750		
He	74	3.3	13			

The volume available for the new gas is 17.5 l.

7. **Load the 17.5 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 17.5 l x 200 bar - 74 sl = 3426 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3426	152.8				
Ar	171.3	7.6	305	20	49	0.219
N2	342.6	15.3	428	67	85	0.529
He	2911	129.9	520	343		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 564KJ. Let's assume 700KJ to account for other heat loss. It is necessary boiling 3.5 Kg (4.4 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 16.8 l.

8. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost sl**	**Total Ar lost sl**
Ar	737	32.9	1314	0.943	0.67	2.86
N2	1475	65.8	1842	2.277		
He	71	3.2	13			

The volume available for the new gas is 16.8 l.

9. **Load the 16.8 l volume of the booster with the gas mixture at 200 bar**

The amount of gas that will enter the booster this time is 16.8 l x 200 bar - 71 sl = 3289 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3289	146.7				
Ar	164.5	7.3	292	19	47	0.210
N2	328.9	14.7	412	64	82	0.508
He	2796	124.7	499	329		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 541KJ. Let's assume 700KJ to account for other heat loss. It is necessary boiling 3.5 Kg (4.4 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 16.1 l.

10. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	901	40.2	1606	1.153	0.64	3.5
N2	1804	80.5	2254	2.786		
He	68	3.0	12			

The volume available for the new gas is 16.1 l.

11. **Load the 16.1 l volume of the booster with the gas mixture at 200 bar**

The amount of gas that will enter the booster this time is 16.1 l x 200 bar - 68 sl = 3152 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3152	140.6				
Ar	157.6	7.0	280	18	45	0.201
N2	315.2	14.1	395	61	79	0.489
He	2679	119.5	478	315		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 518KJ. Let's assume 600KJ to account for other heat loss. It is necessary boiling 3.0 Kg (3.8 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 15.4 l.

12. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1059	47.2	1885	1.353	0.62	4.1
N2	2119	94.5	2646	3.271		
He	65	2.9	12			

The volume available for the new gas is 15.4 l.

13. **Load the 15.4 l volume of the booster with the gas mixture at 200 bar.**

The amount of gas that will enter the booster this time is 15.4 l x 200 bar - 65 sl = 3015 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	3015	134.5				
Ar	150.8	6.7	268	17	43	0.192
N2	301.5	13.5	378	58	76	0.467
He	2563	114.3	457	301		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 495KJ. Let's assume 600KJ to account for other heat loss. It is necessary boiling 3.0 Kg (3.8 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 14.7 l.

14. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1210	54.0	2157	1.548	0.59	4.7
N2	2421	108	3024	3.738		
He	62	2.8	11			

The volume available for the new gas is 14.7 l.

15. **Load the 14.7 l volume of the booster with the gas mixture at 200 bar**

The amount of gas that will enter the booster this time is 14.7 l x 200 bar - 62 sl = 2878 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2878	128.4				
Ar	143.9	6.4	255.7	16	41	0.184
N2	287.8	12.8	358.4	55	73	0.444
He	2446	109.1	436	287		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 472KJ. Let's assume 600KJ to account for other heat loss. It is necessary boiling 3.0 Kg (3.8 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 14.1 l.

16. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1354	60.4	2412	1.732	0.56	5.3
N2	2709	121	3388	4.188		
He	59	2.6	11			

The volume available for the new gas is 14.1 l.

17. **Load the 14.1 l volume of the booster with the gas mixture at 200 bar**

The amount of gas that will enter the booster this time is 14.1 l x 200 bar - 59 sl = 2761 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2761	123.2				
Ar	138	6.2	247.7	15	39	0.178
N2	276	12.3	344.4	53	70	0.426
He	2347	104.7	419	275		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 452KJ. Let's assume 600KJ to account for other heat loss. It is necessary boiling 3.0 Kg (3.8 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 13.5 l.

18. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1492	66.6	2659	1.909	0.54	5.8
N2	2985	133	3724	4.603		
He	57	2.6	11			

The volume available for the new gas is 13.5 l.

19. **Load the 13.5 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 13.5 l x 200 bar - 57 sl = 2643 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2643	118				
Ar	132	5.9	235	14	37	0.169
N2	264	11.8	330	51	67	0.408
He	2247	100.2	401	263		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 432KJ. Let's assume 500KJ to account for other heat loss. It is necessary boiling 2.5 Kg (3.1 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 12.9 l.

20. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1624	72.5	2895	2.078	0.52	6.3
N2	3249	145	4059	5.017		
He	54	2.4	9.6			

The volume available for the new gas is 12.9 l.

21. **Load the 12.9 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 12.9 l x 200 bar - 54 sl = 2643 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2526	113				
Ar	126	5.6	225	13	35	0.169
N2	253	11.3	316	49	64	0.408
He	2147	95.8	383	251		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 412KJ. Let's assume 500KJ to account for other heat loss. It is necessary boiling 2.5 Kg (3.1 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 12.3 l.

22. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1750	78.1	3119	2.239	0.49	6.8
N2	3502	156	4375	5.408		
He	52	2.3	9.3			

The volume available for the new gas is 12.3 l.

23. **Load the 12.3 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 12.3 l x 200 bar - 52 sl = 2406 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2406	107				
Ar	120	5.4	214	12	33	0.154
N2	241	10.8	301	47	61	0.372
He	2045	91.2	365	239		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 392KJ. Let's assume 450KJ to account for other heat loss. It is necessary boiling 2.3 Kg (2.9 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 11.8 l.

24. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1870	83.4	3333	2.393	0.47	7.3
N2	3743	167	4676	5.780		
He	50	2.2	8.9			

The volume available for the new gas is 11.8 l

25. **Load the 11.8 l volume of the booster with the gas mixture at 200 bar**
The amount of gas that will enter the booster this time is 11.8 l x 200 bar - 50 sl = 2310 sl

Gas	sl	mole	g	Heat to cool the gas at 65K KJ	Latent heat of vaporization KJ	Liquid phase l
Total	2310	103				
Ar	116	5.2	207	12	32	0.149
N2	231	10.3	288	45	59	0.356
He	1963	87.6	350	229		

To cool the gas at 65K and to liquefy the Ar and N2 it is necessary to remove 377KJ. Let's assume 450KJ to account for other heat loss. It is necessary boiling 2.3 Kg (2.9 l) of liquid N2. After reaching the equilibrium condition, the pressure of the He fraction at 65K is 43 bar. The volume available for the gas phase is 11.3 l.

26. **Remove the He fraction from the booster**. At the end of this phase the booster contents are:

Gas	sl	mole	g	Liquid phase l	**Ar lost** sl	**Total Ar lost sl**
Ar	1986	88.6	3540	2.541	0.45	7.8
N2	3974	177	4964	6.136		
He	47	2.1	8.4			

The volume available for the new gas is 11.3 l